Wholesomeness of Irradiated Foods 8006

Review of data and concerns raised during the approval process for irradiation of poultry indicates that properly processed irradiated foods are wholesome

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□ THE WHOLESOMENESS (NUTRITIONAL VALUE and lack of mutagenicity, teratogenicity, and toxicity) of irradiated food has been studied extensively (Thayer, 1990). As with any other process, proper food processing conditions must be used. Radiation dose; dose rate; temperature and atmosphere during irradiation; and duration, temperature, and atmosphere during storage all can affect the outcome with specific foods (Thayer, 1990). Radiolytic changes in foods are minimal and are predictable from the radiation chemistry of the principal components of the food. Furthermore, the radiolytic products are neither unique nor toxicologically significant in the quantities found in irradiated foods (Chinn, 1977, 1979a, b; Diehl, 1990; Swallow, 1991; Urbain, 1986).

Food cannot become radioactive from exposure to gamma rays from cobalt-60, X-rays of 5 MeV or less, or accelerated electrons with energy levels below 10 MeV (Becker, 1983). Irradiation of red meat and poultry meat can provide products to the consumer, with greatly reduced or completely eliminated risk of encountering a foodborne pathogen (Thayer, 1990).

This article will review the data cited by the Food and Drug Administration in support of the approval (FDA, 1990; FSIS, 1992) of irradiation of poultry meat at 1.5–3.0 kGy to control foodborne pathogens and its commercial introduction in the United States. For this technology to be appropriate, it must control the target spoilage and pathogenic organisms and not adversely affect the wholesomeness of the food product. Any effects on the nutritional value and sensory properties of the treated food must be within acceptable limits. The marketplace defines what sensory changes, and the regulatory agencies what nutritional changes, are acceptable.

Studies on Chicken

Eekelen et al. (1971) conducted a multigenerational study of albino rats consuming radiation-pasteurized chicken as 35% dry matter in their diet. The three diets were a nonirradiated control, a diet with chicken irradiated to 3 kGy, and a diet with chicken irradiated to 6 kGy. The diets were fed to 10 male and 20 female rats in the F_0, F_1, and F_2 generations. Two litters were reared in each of the three generations. A complete subchronic 90-day feeding study was conducted with the second litter of the third generation. No deleterious effects were found in rats fed the irradiated chicken.

Eekelen et al. (1972) conducted a chronic two-year feeding study of gamma-irradiated chicken with albino rats. The two control diets were a stock rat feed and nonirradiated chicken at 35% dry matter in the diet. The experimental diets contained chicken irradiated to either 3.0 kGy or 6.0 kGy at 35% dry matter. Each of the diets was fed to 60 male and 60 female rats. The general appearance and behavior, mortality, growth, food intake, and hematological factors and clinical constituents of the blood and urine were measured. The animals were sacrificed at two years and examined for any pathology. No treatment-related effects were found.

Til et al. (1971) conducted a one-year feeding study of beagle dogs fed chicken irradiated to an absorbed dose of either 3.0 or 6.0 kGy or nonirradiated chicken. Each test group consisted of four male and four female dogs that were fed the test diet at a level of 35% dry matter. No treatment-related deleterious effects were noted in appearance, behavior, growth, hematology, urology, and gross and or microscopic pathology upon autopsy at 52 weeks.

Thayer et al. (1987) reported the results of nutritional, genetic, teratogenic, and multigeneration feeding studies of frozen enzyme-inactivated chicken meat, thermally sterilized chicken meat, gamma-sterilized enzyme-inactivated chicken meat, and electron-sterilized enzyme-inactivated chicken meat. These studies were initiated by the U.S. Army in 1976 and completed under the supervision of the U.S. Dept. of Agriculture. They required 135,405 kg of chicken that was enzyme inactivated by heating to an internal temperature of 75–80°C. The irradiated chicken received a dose of 45–68 kGy administered in vacuo at an initial temperature of −40°C; this is far in excess of the currently approved 3.0 kGy.

The animals were fed chicken at a level of 35% of total dry matter except that teratogenic studies included groups that were fed chicken at a level of 70% of total dry matter. Teratogenic studies were conducted with mice, hamsters, rats, and rabbits. Four genetic toxicology tests were conducted: a test for mutagenic activity using the *Salmonella*/mammalian microsome mutagenicity assay; a test for sex-linked recessive lethal mutations in *Drosophila melanogaster*; a test for heritable translocations in CD-1 mice; and a dominant lethal assay with pregnant mice. In the last test, the positive control failed to induce a response and thus could not be evaluated. No evidence of genetic toxicity or teratogenic effects was observed.

Two significant chronic feeding studies were completed during the study: a 40-month chronic feeding and breeding performance study in beagle dogs and a 2-year chronic toxicity, oncogenicity, and multigeneration reproductive study with CD-1 mice. Beagle dogs were fed the test or control diets beginning in utero until death or sacrifice (at 36 mo after weaning for females, 40 for males). The 20 female F_0 dogs were bred on successive estrus periods with the 10 males to produce the maximum number of litters before the end of the study. The F_1 weanlings ate the diets for 6 mo. General appearance and behavior, mortality, growth, food intake, and hematological and urological factors were observed during the study. Extensive gross and microscopic pathological examinations were conducted at the death or sacrifice of each animal. No overt signs of toxicity due to ingestion of any of the diets were observed. Males fed the gamma-irradiated chicken had a lower body weight than those fed the frozen control chicken, which were considered obese. The F_0 females fed the gamma-irradiated meat had greater fecundity. Neither treatment-related abnormalities nor evidence of reproductive toxicity was observed.

Albino CD-1 mice were placed on one of the four diets and maintained on it for 10 weeks prior to the birth of the F_0 litters. Then 115 pairs were selected for each diet group except the frozen control diet, for which 175 pairs were selected. The F_0 generation was continued on the test or control diet for 24 mo after weaning. Cohorts of the F_0 mice were bred to begin the three-generation reproduction study, then returned to the chronic feeding study after weaning of the F_{1b} litter. The animals were exposed to the test or control diets beginning in utero and continuing until death or scheduled termination. The same types of analyses were performed as in the beagle

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study. The overall conclusion was that there was no evidence of treatment-related abnormalities in the animals.

Incidental evidence of the wholesomeness of irradiated foods is provided by the routine use of radiation-sterilized feeds by toxicology groups to obtain better and more reproducible results than obtained with other laboratory feeds. In a study in England, 40 generations of 2,000 mice were routinely fed diets irradiated to doses of 50 kGy with no evidence of genetic, teratogenic, or other abnormalities (Swallow, 1991).

In a feeding trial in China, 21 male and 22 female volunteers consumed 62–71% of their total caloric intake as irradiated foods for 15 weeks (Chi et al., 1986). The diet included rice irradiated to 0.37 kGy and stored for 3 mo; rice irradiated to 0.4 kGy and stored for 2 weeks; meat products such as pork sausage irradiated to 8 kGy and stored at room temperature for 2 weeks; and 14 different vegetables irradiated to 3 kGy and stored at room temperature for 3 days. A double-blind design was used and included measurements of total caloric intake, monthly biochemical and physical exams, and sensory evaluations of the food. The diet was well received, and there were no adverse findings associated with the consumption of irradiated foods.

Concerns Regarding Irradiation

A frequently voiced concern is the effect of food irradiation on critical nutrients in food. Fox et al. (1989) reported the effects of gamma irradiation at doses up to 6.65 kGy at −20 to 20°C on the thiamin, niacin, and riboflavin content of chicken breasts and on the thiamin, niacin, pyridoxine, and cobalamin content of pork chops. Thiamin was the only vitamin for which significant losses were observed. Furthermore, the rate of loss of thiamin in chicken was approximately half that in pork. The authors concluded that vitamin losses from chicken at doses up to 3 kGy (8.6%) and from pork at up to 1 kGy (17.6%) were not of nutritional significance.

A large-scale toxicology study of radiation-sterilized chicken (Thayer et al., 1987), provided a unique opportunity to compare the effects of four processing techniques on nutrients in the enzyme-inactivated meat. The meat was purchased in three different lots and was subjected to extensive analyses of nutrients after freezing (control), thermal sterilization, gamma sterilization, or electron sterilization (Thayer, 1990). There were no adverse treatment-related effects on the percentages of the individual amino acids, individual fatty acids, free fatty acid, crude fat, peroxide value, riboflavin, pyridoxine, niacin, pantothenic acid, biotin, folic acid, choline, vitamin A, vitamin D, vitamin K, and vitamin B_{12}. The amounts of thiamin in the thermal- and gamma-processed products (1.53 and 1.57 ppm, respectively) were significantly lower ($p<0.01$) than in the frozen control and electron-sterilized products (2.31 and 1.98 ppm, respectively). The 32% loss of thiamin from frozen, vacuum-packed, enzyme-inactivated chicken meat during radiation sterilization was less than the 40% loss in chicken breast meat irradiated to 6.6 kGy at 0°C in the presence of air and then cooked (Fox et al., 1989); this illustrates the effect processing conditions can have on the final product.

There are questions about other irradiated products that need to be addressed, in particular the potential loss of vitamin C from fruit or vegetables irradiated for insect control. This issue is complicated because fruits and vegetables are living tissue. Ascorbic acid is a sensitive redox compound. Even at doses below 1 kGy, such as those approved for insect control, some ascorbic acid will be converted to its oxidized dehydro form (Romani et al., 1963). Dehydroascorbic acid, however, is fully as active as the reduced form of the vitamin. Unfortunately, many of the studies in the literature did not use assay methods that would detect the oxidized form of the vitamin and thus reported erroneously high losses. During storage of irradiated potatoes, much of the dehydro form is converted back to the reduced form. However, in selected products, some loss appears to be irreversible, especially at radiation doses >1 kGy (Thayer et al., 1991). These losses do not appear to be significant at doses intended to control insects in fruits (<1 kGy) and are lower than those from freezing (Beyers and Thomas, 1979).

There is a concern that ionizing radiation creates free radicals, and that they may be present in the food at the time of ingestion. Free radicals are also produced by most other food processing techniques. By their very nature, free radicals are extremely reactive in most products at temperatures above freezing. Taub et al. (1978) found that even at −10°C the lifetime of free radicals in meat was less than 8 hr. Free radicals do not appear to be of any physiological or toxicological significance, even in very dry products, in which they would be expected to have long half-lives. Renner and Reichelt (1973) detected no treatment-related effects in rats that had consumed for a period of 3 years milk powder that had been irradiated to 45 kGy.

It was of concern that ionizing radiation might produce peroxides and hydroperoxides in foods, and high peroxide values were found in irradiated herring (Gower and Wills, 1986). However, irradiated fatty fish have been fed to test animals without evidence of toxicological effects (Nadkarni, 1980). The total fat content of the radiation-sterilized chicken used in the studies described above was 12–13%, and the products were stored at room temperature following sterilization. The peroxide values of these irradiated meats were not elevated compared to the nonirradiated meat, and there was no evidence of toxic effects from their long-term ingestion (Thayer et al., 1987; Thayer, 1990).

Bhaskaram and Sadasivan (1975) reported that children suffering from kwashiorkor developed an incidence rate of polyploidy of 0.8% after 2 weeks of ingestion of irradiated wheat, and 1.8% after 4 weeks. Vijayalaxmi (1975, 1976) reported increased polyploid cells in mice and rats eating irradiated wheat. These reports caused considerable concern in the scientific community but were found to contain mutually contradictory data and to be at variance with well-established knowledge of biology (Kesavan and Sukhatame, 1976; FDA, 1986). An example of this was the report of 0% polyploidy in controls and test group children after removal of the treated diet (Bhaskaram and Sadasivan, 1975), even though polyploidy is not unusual in human populations. George et al. (1976) found no evidence for increased polyploid cells in the bone marrow of rats fed 0.75 kGy-irradiated wheat within 24 hr of irradiation for 1–6 weeks.

Tesh et al. (1977) reported the results of duplicate studies of rats consuming a diet incorporating irradiated wheat that were conducted independently at different laboratories. The diets contained 70% by weight of wheat flour that was irradiated to 0.75 kGy prior to milling. The diets were consumed by the rats within 2, 4, or 8 weeks from the date of irradiation. There were 5 males and 5 females in each diet group in each study. The number of polyploid configurations per 500 metaphases were counted for each animal. There were no treatment-related effects on the number of polyploids per 500 metaphases, food consumption, body weight change, and incidence of mortalities.

Chi et al. (1986) specifically looked for any evidence of polyploid cells in the human volunteers ingesting irradiated diets without finding such evidence; however, the study design may have been inadequate to detect abnormalities below the 1% level because only 50 metaphase lymphocytes were examined for each subject.

Renner (1977) examined metaphase preparations of chromosomes from bone marrow cells of Chinese hamsters for evidence of mutagenic effects following the ingestion of an unirradiated diet or a radiation-sterilized diet (45 kGy) for 6 weeks and found incidences of 0.06% and 0.32% polyploid cells, respectively. In the initial investigations, 100 metaphases were counted per animal, and 300 in subsequent studies. The incidence of structural chromosomal aberrations did not increase. Further studies revealed that animals ingesting feed immediately after irradiation at doses of 20 kGy or higher developed increased rates of polyploidy. The incidence did not increase when doses of 100 kGy were used and never exceeded 0.5%. No such effect was found at doses of 10 kGy or less and when the irradiated feed was stored for 6 weeks before use. The ingestion of small amounts of 0.3% H_2O_2 with the unirradiated diet also produced an increased incidence of polyploidy. Because the incidence of polyploidy returned to the control level within a maximum of 6 weeks and because the effect was not dose related, the author concluded that the result was not a mutagenic effect.

Irradiated Foods Are Wholesome

Neither short nor multigeneration feeding studies have produced evidence of toxicological effects in mammals due to their ingestion of irradiated foods. The data support the conclusion that properly processed irradiated foods are wholesome.

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